SYSTEM AND METHOD FOR STEPPED CAPACITY MODULATION IN A REFRIGERATION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/442,215, filed January 24, 2003.

BACKGROUND OF THE INVENTION

[0002] The present invention relates generally to a refrigeration system having stepped output capacities. More specifically, the present invention is directed to a control system that can provide eight or more discrete output capacities for a refrigeration system having two or more multi-capacity compressors.

[0003] Dual capacity compressors have been used to provide to different levels of output capacity for a refrigeration system. One drawback of using a dual capacity compressor is that the refrigeration system may require an output capacity that is different from one of the capacities of the compressor, thereby resulting in the generation of excess capacity on the one hand or the generation of insufficient capacity on the other hand depending on the selected configuration of the compressor.

[0004] In addition, different levels of output capacity for a refrigeration system can be obtained by controlling the operation of multiple single capacity compressors incorporated in the refrigeration system. One such system is discussed in U.S. Patent No. 4,384,462 (the '462 Patent). The '462 Patent is directed to a multiple-compressor refrigeration system having a plurality of compressors of unequal capacity and a plurality of evaporators in different enclosures connected to the compressors. The compressors have a single capacity and can be switched between an "on" state and an "off" state. The switching of the compressors between the "on" and "off" states in different combinations results in 2^N different levels or operating states for the refrigeration system, including a zero state where all compressors are "off." The control can increment or decrement the particular operating state of the refrigeration system in response to an increase or decrease of the suction pressure of the system.

[0005] Furthermore, different levels of output capacity for a refrigeration system can be obtained by sequencing the operation of multiple dual capacity compressors incorporated in the refrigeration system. One such system is discussed in U.S. Patent No. 4,501,125 (the '125 Patent). The '125 Patent is directed to a temperature conditioning system. The temperature conditioning system can incorporate two dual-stage compressors connected in a refrigeration circuit to an evaporator. The '125 Patent discusses the availability of four stages of cooling when using two dual-stage compressors. The system increments or decrements stages or states of cooling (or heating) in response to predetermined criteria in a look-up table.

[0006] Therefore what is needed is a system and method for providing a stepped output capacity in a refrigeration system having two or more multi-capacity compressors to provide the appropriate output capacity to satisfy a particular output capacity required by the refrigeration system.

SUMMARY OF THE INVENTION

[0007] One embodiment of the present invention is directed to a refrigeration system having a plurality of compressors. Each compressor of the plurality of compressors is configured to provide a plurality of discrete output capacities. The refrigeration system also includes a condenser in fluid communication with the plurality of compressors and at least one evaporator in fluid communication with the condenser and with the plurality of compressors. A control system is used to control the operation (starting or stopping) of each compressor of the plurality of compressors and to control a discrete output capacity of the plurality of discrete output capacities for each compressor of the plurality of compressors. The control system determines the compressors to operate and the discrete output capacity of each operating compressor of the plurality of compressors in response to a required output capacity of the refrigeration system.

[0008] Another embodiment of the present invention is directed to a method of controlling the operation of a plurality of multi-capacity compressors in a refrigeration system having at least one evaporator. The method includes the steps of

determining an amount of output capacity required by a refrigeration system and determining a configuration of a plurality of multi-capacity compressors to generate the determined amount of output capacity. The determined configuration of the multi-capacity compressors is obtained from a table having a plurality of configurations of compressor operation and compressor capacity for the plurality of multi-capacity compressors. Each configuration of the plurality of configurations corresponds to an output capacity of the refrigeration system. The method also includes the step of applying the determined configuration of the plurality of multi-capacity compressors to the plurality of multi-capacity compressors to generate the determined amount of output capacity in the refrigeration system.

[0009] A further embodiment of the present invention is directed to a refrigeration system having a plurality of compressors, a condenser in fluid communication with the plurality of compressors, at least one evaporator in fluid communication with the condenser and with the plurality of compressors, and a control system to control the plurality of compressors in response to a required output capacity for the refrigeration system. The plurality of compressors have a plurality of predetermined operating configurations, wherein each predetermined operating configuration of the plurality of predetermined operating configurations results in a predetermined output capacity for the refrigeration system. The control system is configured to select a predetermined operating configuration from the plurality of predetermined operating configurations that most efficiently satisfies the required output capacity. Each compressor of the plurality of compressors has a plurality of discrete output capacities and each predetermined operating configuration for the plurality of compressors includes an operational state for each compressor of the plurality of compressors and a discrete output capacity for each operating compressor.

[0010] Still a further embodiment of the present invention is directed to a method of controlling the operation of a plurality of multi-capacity compressors in a refrigeration system. The method includes the steps of providing a refrigeration system having a plurality of multi-capacity compressors, a condenser and a plurality of evaporators connected in a closed refrigerant circuit and determining an amount of output capacity required by the refrigeration system. The method also includes the

step of determining a configuration of the plurality of multi-capacity compressors having a predetermined output capacity to satisfy the determined amount of required output capacity. Each multi-capacity compressor of the plurality of multi-capacity compressors has a plurality of discrete output capacities and the determined configuration of the plurality of multi-capacity compressors includes an operational state for each compressor of the plurality of multi-capacity compressors and a discrete output capacity for each operating multi-capacity compressor. The method further includes the step of generating control instructions corresponding to the determined configuration of the plurality of multi-capacity compressors to control the plurality of multi-capacity compressors to generate the predetermined output capacity for the refrigeration system.

[0011] One advantage of the present invention is that a variety of different output capacities can be provided to more closely match the output capacity required by the refrigeration system thereby avoiding the generation of excess capacity that is not used.

[0012] Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Figure 1 illustrates schematically one embodiment of a refrigeration system of the present invention.

[0014] Figure 2 is a table showing the output capacity steps and the corresponding configurations of two dual capacity compressors generated by the control system of the present invention.

[0015] Figure 3 is a table showing the output capacities provided by several different compressor configurations.

[0016] Figure 4 is a flowchart of the control process of the present invention.

[0017] Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

DETAILED DESCRIPTION OF THE INVENTION

[0018] A general system to which the present invention can be applied is illustrated, by means of example, in Figure 1. As shown, the heating, ventilation and air conditioning (HVAC) or refrigeration system 100 includes a first compressor 102, a second compressor 104, a condenser 106, one or more evaporators 108, an expansion device(s) 110 and a control panel 140. The control panel 140 can include an analog to digital (A/D) converter, a microprocessor, a non-volatile memory, and an interface board. The operation of the control panel 140 will be discussed in greater detail below. The conventional refrigeration or HVAC system 100 includes many other features that are not shown in Figure 1. These features have been purposely omitted to simplify the drawing for ease of illustration.

[0019] In the refrigeration system 100, the compressors 102 and 104 compress a refrigerant vapor and deliver the compressor refrigerant vapor over a single line to the condenser 106. The outputs of the compressors 102 and 104 are connected to one another such that the compressed refrigerant vapor from each of the compressors 102 and 104 is combined into a single line for subsequent transport to the condenser 106. Further, in a situation where only one of the compressors 102 and 104 is in operation, the output of the other compressor 102 and 104 is closed or sealed by a valve (not shown) to prevent backflow of refrigerant through the non-operating compressor 102 and 104. The compressors 102 and 104 are preferably any type of reciprocating or scroll compressors that have a multi-capacity output, i.e., two or more discrete output capacity levels. However, it is to be understood that the present invention can be used with any type of compressor that can be configured to provide two or more discrete output capacities.

[0020] In another embodiment of the present invention, the compressed refrigerant vapor output from each of the compressors 102 and 104 can be transported separately and remain separate until the refrigerant vapor output is combined in the

condenser 106. In still another embodiment of the present invention, the compressed refrigerant vapor output from each of the compressors 102 and 104 can be transported in separate refrigerant circuits, i.e. the compressed refrigerant vapor from one compressor is not mixed with the compressed refrigerant vapor from the other compressor as the refrigerant is circulated through the system. In this embodiment, the condenser and evaporators for each circuit can have any suitable arrangement that permits the necessary heat exchanges while still maintaining the separate refrigerant circuits.

[0021] In Figure 1, the refrigerant vapor from the compressors 102 and 104 flowing through or around a heat-exchanger coil in the condenser 106 enters into a heat exchange relationship with a fluid, preferably air or water. The refrigerant vapor in the condenser 106 undergoes a phase change to a refrigerant liquid as a result of the heat exchange relationship with the fluid. The condensed liquid refrigerant from condenser 106 flows through an expansion device(s) 110 to the evaporators 108. The expansion device(s) 110 can be any type of acceptable device that can convert a high pressure liquid to a low pressure liquid and vapor such as an expansion valve or capillary tube.

[0022] The output of the expansion device(s) 110 is then provided to one or more evaporators 108 depending on the particular configuration of the refrigeration system 100. One or more of the evaporators 108 may be shut down or inactive, depending on the particular cooling demands or output capacity requirements of the refrigeration system 100 (to be discussed in greater detail below). Refrigerant liquid and/or vapor is prevented from entering the inactive evaporators 108 by valves (not shown) at the inlet and outlet of each of the inactive evaporators 108. In another embodiment of the present invention, the line from the expansion device 110 can be connected to a manifold with appropriate valves that are connected to each of the evaporators 108. The manifold can then be configured or operated to provide refrigerant to the appropriate evaporators 108. Similarly, the outputs of the evaporators 108 can be connected to a manifold with appropriate valves, which manifold can then be configured or operated to provide refrigerant vapor to the compressors 102 and 104 using only a single line. The inactivation of the evaporators 108 and the closing of

the valves, whether in separate lines or in a manifold, can be controlled by a central control system or individually at each of the evaporators 108.

[0023] The refrigerant liquid and vapor from the expansion device 110 flowing through or around a heat-exchanger coil in each of the active evaporators 108 enters into a heat exchange relationship with a fluid, preferably air, to chill the temperature of the air. The refrigerant liquid in the evaporators 108 undergoes a phase change to a refrigerant vapor as a result of the heat exchange relationship with the air. The vapor refrigerant in the evaporators 108 exits the evaporators 108 through suction connections and returns to the compressors 102 and 104 by a common line to complete the cycle. The number of evaporators 108 in the refrigeration system 100 can vary from one to N, wherein N is preferably a number corresponding to the maximum number of stepped outputs from the compressors 102 and 104 (discussed in greater detail below). However, in another embodiment of the present invention, the number of evaporators can be greater than the number of stepped outputs from the compressors 102 and 104, i.e., N is greater than the maximum number of stepped outputs. In this embodiment, the evaporator output would not match the compressor output, as in the embodiment where the number of stepped outputs and the number of evaporators were the same. For example, if compressors 102 and 104 in Figure 1 are both dual capacity compressors, then N is preferably eight (see Figure 2) and eight (or possibly more) evaporators 108 can be accommodated in the refrigeration system 100.

[0024] In other embodiments of the present invention, the number of compressors 102 and 104 can be increased and/or the number of capacities provided by each of the compressors 102 and 104 can be increased to increase the overall number of steps of output capacity available in the refrigeration system 100 (discussed in greater detail below). Correspondingly, as the number of output capacity steps increases, so does the preferred number (N) of evaporators 108 that can be used in the refrigeration system 100 such that the preferred ratio of one evaporator to one output capacity step is maintained.

[0025] The control panel 140 has an A/D converter to preferably receive input signals from the system 100 that indicate the performance of the system 100. The

control panel 140 also has an interface board to transmit signals to components of the system 100 to control the operation of the system 100. For example, the control panel 140 can transmit signals to control the number of active evaporators and to control the operation of the compressors 102 and 104. The control panel 140 may also include many other features and components that have not been discussed herein. These features and components have been purposely omitted to simplify the control panel 140 for ease of discussion.

[0026] The control panel 140 is part of a control system that uses control algorithm(s) or software to control operation of the system 100 and to determine and implement an operating configuration for the compressors 102 and 104 in response to a particular output capacity requirement for the system 100. Additionally, the control system can use the control algorithm(s) to open and close valves to engage or activate and disengage or deactivate evaporators 108. In one embodiment, the control algorithm(s) can be computer programs or software stored in the non-volatile memory of the control panel 140 and can include a series of instructions executable by the microprocessor of the control panel 140. While it is preferred that the control algorithm be embodied in a computer program(s) and executed by the microprocessor, it is to be understood that the control algorithm may be implemented and executed using digital and/or analog hardware by those skilled in the art. If hardware is used to execute the control algorithm, the corresponding configuration of the control panel 140 can be changed to incorporate the necessary components and to remove any components that may no longer be required.

[0027] The control system of the present invention generates the different steps of output capacity for the refrigeration system 100 by controlling which compressors 102 and 104 are in operation at a particular time and by controlling the output capacity of the compressors 102 and 104 that are in operation. By controlling the operation of the compressors and their output capacities, the control system of the present invention can generate different steps of output capacities for the refrigeration system 100. The operating configurations of the compressors 102 and 104 from Figure 1 for obtaining the eight discrete steps is shown in Figure 2. The compressors 102 and 104 from Figure 1 are dual capacity compressors having a first stage that

provides half of the total output capacity of the compressor 102 and 104 and a second stage that provides the total output capacity of the compressor 102 and 104. As can be seen in Figure 2, four discrete steps are generated or obtained by operating one of the compressors 102 and 104 in one of its two operating modes. The other four steps are generated or obtained by operating both of the compressors 102 and 104 in one of their two operating modes. It is to be understood that a particular configuration of the compressors 102 and 104 can be correlated to any particular step and the correlation shown in Figures 2 and 3 is for illustrative purposes only. However, it is preferred that the steps are sequentially identified in order of increasing system capacity.

[0028] When additional compressors are added to the refrigeration system 100, the control system of the present invention (and the control chart in Figure 2) is expanded to provide additional control configurations for the new compressor(s). For example, the addition of a new compressor can generate new steps for the first stage output and second stage output of the new compressor and new steps combining the output of the new compressor with the output of one or both of the compressors 102 and 104. Similarly, if one of the compressors 102 and 104 is replaced with a multi-capacity compressor having three or more discrete output capacities, the control system of the present invention (and the control chart in Figure 2) is expanded to provide additional control configurations for the new compressor capacities.

[0029] To further illustrate the operation of the control system of the present invention, the output capacity steps of Figure 2 are applied to several different compressor 102 and 104 configurations. Figure 3 provides the output capacity of each of the eight steps for four different compressor configurations. The four different compressor configurations include: a configuration where one compressor provides 40% total system capacity and the other compressor provides 60% total system capacity, e.g. a 2-ton capacity compressor and a 3-ton capacity compressor; a configuration where one compressor provides 30% total system capacity and the other compressor provides 70% total system capacity, e.g. a 1-ton capacity compressor and a 2 1/3-ton capacity compressor; a configuration where one compressor provides 20% total system capacity and the other compressor provides 80% total system capacity, e.g. a 1-ton capacity compressor and a 4-ton capacity compressor; and a configuration

where each compressor provides 50% of the total system capacity, e.g. a pair of 2-ton capacity compressors.

[0030] As can be seen in Figure 3, when different capacity compressors 102 and 104 are used with the control system of the present invention eight different output capacities are generated by the eight steps or configurations. However, when the compressors 102 and 104 have the same output capacity only four different output capacities are generated by the eight steps or configurations. This is because several of the steps generate the same output capacity. Thus, in a preferred embodiment of the present invention, the compressors 102 and 104 have different output capacities in order to obtain the maximum number of output capacity steps. The determination and selection of the particular total output capacities of the compressors 102 and 104 is based on the maximum and minimum requirements of the refrigeration system 100 and on the particular output capacity steps desired by the user.

[0031] Figure 4 illustrates the process for determining the appropriate output capacity for the refrigeration system 100. The process begins at step 402 where the required output capacity for the refrigeration system 100 is determined. The required output capacity of the refrigeration system 100 is related to the cooling demand placed on the evaporator(s) 108. The cooling demand can be a function of the temperature of the fluid to be cooled, a function of the number of active evaporators, a combination of the two or any other suitable factor. For example, in the refrigeration system 100 shown in Figure 1, the cooling demand could be based on five of the evaporators 108 being active while the other three evaporators 108 are inactive. This may occur in a situation such as may be found in a building, wherein each evaporator 108 is providing cooling to a particular area of the building.

[0032] Once the output capacity for the refrigeration system 100 is determined in step 402, the control system then determines in step 404 the configuration of the compressors 102 and 104 that best satisfies or most efficiently satisfies this required output capacity. The control system evaluates the stored information on the compressor configurations, such as the information in Figure 2, to determine appropriate compressor configuration. The information on the compressor

configurations can be stored in any suitable way for quick and easy retrieval by the control system. The information can be stored in a table, a database or any other suitable configuration. In one embodiment, the control system can correlate the number of active evaporators 108 to a corresponding step having a configuration to generate the appropriate output capacity. Referring back to the above example with five active evaporators 108, the control system can select step 5, which matches the number of active evaporators 108 and has a compressor configuration that generates the appropriate output capacity. In another embodiment, the control system can compare the required output capacity to each of the particular configurations and the corresponding capacities to determine which configuration and capacity best matches the required output capacity. For example, if the required output capacity corresponds to 50% total capacity, the control system would compare the output capacity for each of the configurations to determine the configuration that is closest to providing the 50% required output capacity.

[0033] Finally, in step 404, the control system takes the determined compressor configuration and generates the appropriate control signals for the compressors 102 and 104. The compressors 102 and 104 are then operated in the desired configuration to obtain the desired output capacity in response to the control signals generated by the control system.

[0034] While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.